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6. AUTHOR(S)

Leon O. Chua

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Electronics Research Laboratory
Cory Hall
University of California
Berkeley, CA 94720-1774

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We have made impressive research progress on several related aspects of our research grant during the period; namely, 1) robustness of chaotic synchronization schemes, 2) efficiency of chaotic synchronization systems, 3) design of practical chaotic spread-spectrum communication systems, 4) channel capacity of chaotic spread-spectrum communication systems, and 5) potential commercial applications of chaotic spread-spectrum communication systems.

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Progress Report on ONR Grant Number N00014-96-1-0753:
"Exploiting Chaos for Spread-Spectrum Communications"

Leon O. Chua

Electronics Research Laboratory,
Department of Electrical Engineering and Computer Sciences,
University of California at Berkeley, Berkeley, CA 94720, USA

We have made impressive research progress on several related aspects of our research grant during the period July, 1997 through June 1998; namely, 1) robustness of chaotic synchronization schemes, 2) efficiency of chaotic synchronization systems, 3) design of practical chaotic spread-spectrum communication systems, 4) channel capacity of chaotic spread-spectrum communication systems, and 5) potential commercial applications of chaotic spread-spectrum communication systems.

In the area of robustness of chaotic synchronization schemes, we have developed a rigorous theory of H_∞ robustness for chaotic synchronization of two chaotic systems. This theory is indispensable for designing robust transmitters and receivers for chaotic spread-spectrum communications.

To enhance the competitive edge of chaotic spread-spectrum communication systems over current commercial CDMA systems, the bandwidth for transmitting the chaotic synchronization signals must be reduced significantly. We have made a major breakthrough on this critical issue by inventing a totally new chaotic synchronization scheme called "impulsive chaotic synchronization". Unlike other chaotic synchronization schemes, which are based on ordinary differential equations(or difference equations), our impulsive synchronization approach is based on the recently developed mathematical theory of impulsive differential equations. Although impulsive synchronization appears to be intuitively possible, no theoretical analysis had been made prior our invention. We have just published a rigorous theoretical foundation of our invention and have presented experimental confirmation on the impulsive synchronization of two Chua's oscillators. Based on our impulsive synchronization scheme, the bandwidth of the transmitted synchronization signals can be reduced by at lease 30,000 times compared to other state-of-the-art **continuous** chaotic synchronization schemes. The channel bandwidth problem which had haunted many previous synchronization schemes has now been successfully solved because our impulsive synchronization signals are transmitted **digitally**. Our chaotic impulsive synchronization scheme also makes it possible for a complete **digital** implementation of the baseband chaotic components for both transmitters and receivers.

Our research on the above cited chaotic impulsive synchronization scheme has led to the invention of a brand new technology called "Chaotic Digital Code-Division Multiple Access for Wireless Communication Systems". A patent based on this invention has recently been

filed by the University of California, Office of Technology Licensing, under Case No. B-97-080. We have demonstrated by extensive computer simulations that chaotic digital CDMA communications based on our chaotic impulsive synchronization technology can double the channel capacity of CDMA in wireless environments. In addition, chaotic digital CDMA systems can also be used in cable TV networks for Internet access via coaxial cables. Comparing to the current **synchronous** CDMA scheme used in cable TV networks for Internet access, our **non-synchronous** chaotic digital CDMA can provide at least a 1.5 times bigger channel capacity.

The key concept of our chaotic digital CDMA system consists of substituting the **chaotic carrier** generator for both the chip generator and the carrier generator required in current CDMA systems. This significantly simplifies the hardware complexity of both transmitters and receivers, thereby making it possible to design other novel applications, such as home automation via power-line carriers. Because the high-frequency chip sequence has been eliminated, our chaotic digital CDMA system can work in a unique mode, called the **interleave** mode, where the transmitter has to transmit only a small portion of the entire message bit duration. By doing so, the interference level within each cell is reduced significantly. This results in a bigger global channel capacity for chaotic digital communication systems. Because of the relatively low efficiency of the power amplification stage in RF transmitters, the interleave mode will result in a considerable longer battery life than conventional CDMA systems. This advantage is particularly important for mobile stations in wireless environments.

Our future research will exploit our above cited inventions to other applications. We will also conduct even more extensive computer simulations under more realistic and noisy environments.

Publications:

1. Kapitaniak, T., Chua, L.O. and Zhong, G.-Q. "Experimental evidence of locally intermingled basins of attraction in coupled Chua's circuits." *Chaos, Solitons and Fractals*, Sept. 1997, vol.8, (no.9):1517-22.

2. Suykens, J.A.K., Curran, P.F., Vandewalle, J. and Chua, L.O. "Robust nonlinear H_∞ synchronization of chaotic Lur'e systems." *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, Oct. 1997, vol.44, (no.10):891-904.

3. Kolumban, G., Kennedy, M.P. and Chua, L.O. "The role of synchronization in digital communications using chaos. I . Fundamentals of digital communications." *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, Oct. 1997, vol.44, (no.10):927-36.

4. Tao Yang and Chua, L.O. "Impulsive stabilization for control and synchronization of chaotic systems: theory and application to secure communication." *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, Oct. 1997, vol.44, (no.10):976-88.

5. Suykens, J.A.K., Curran, P.F., Tao Yang, Vandewalle, J. and Chua, L.O. "Nonlinear H_∞ synchronization of Lur'e systems: dynamic output feedback case." *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, Nov. 1997, vol.44, (no.11):1089-92.

6. Guo-Qun Zhong, Chai Wah Wu and Chua, L.O. "Torus-doubling bifurcations in four mutually coupled Chua's circuits." *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, Feb. 1998, vol.45, (no.2):186-93.

7. Gang Hu, Jinghua Xiao, Chua, L.O. and Pivka, L. "Controlling spiral waves in a model of two-dimensional arrays of Chua's circuits." *Physical Review Letters*, 2 March 1998, vol.80, (no.9):1884-7.

8. A.I. Panas, T. Yang and Leon O. Chua, "Experimental Results of Impulsive Synchronization Between Two Chua's Oscillators", *International Journal of Bifurcation and Chaos*, vol.8, no.3, March 1998.

9. J.A.K. Suykens, T. Yang and Leon O. Chua, "Impulsive synchronization of chaotic Lur'e systems by measurement feedback," *International Journal of Bifurcation and Chaos*, vol.8, no.6,June 1998.

10. T. Yang and Leon O. Chua, "Error Performance for Chaotic Digital Code-Division Multiple Access(CDMA)," *International Journal of Bifurcation and Chaos*, 1998(in press).

11. T. Yang and Leon O. Chua, "Applications of Chaotic Digital Code-Division Multiple Access(CDMA) to Cable Communication Systems," *International Journal of Bifurcation and Chaos*, 1998(in press).

12. T. Yang, J.A.K. Suykens and Leon O. Chua, "Impulsive Control of Nonautonomous

Chaotic Systems Using Practical Stabilization," *International Journal of Bifurcation and Chaos*, 1998(in press).